

- 1 -

HEAT-TRANSPORT DEVICE, METHOD FOR MANUFACTURING THE SAME,
AND ELECTRONIC DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to measures against gas that accumulates in a line or the like in a heat-transport device or a heat-transport mechanism included in an electronic device such as a computing or an imaging device.

2. Description of the Related Art

In a heat-pipe device for dissipating heat or cooling, surface oxidation is known as a measure in order to reduce gas such as oxygen or hydrogen that accumulates in a condenser. For example, referring to Japanese Unexamined Patent Application Publication Nos. 9-273882 (Figs. 1 and 2) and 11-304381 (Figs. 2 and 3).

In recent years, by developing of technology for an electronic device and a micromachine, a compact device can be manufactured; hence, technology for micro-electro-mechanical systems (MEMS) has been receiving attention and been studied for applying a heat-transport device. As a background to this study, a system that is suitable for cooling a heat source in a small and a high-performance electronic device is required. And there is also the necessity for efficiently dissipating heat generated in a

device such as a central processing unit (CPU) which has significantly improved processing-speed.

In a capillary pumped loops (CPLs) structure, for example, a cycle involving the evaporation of a refrigerant at an evaporator to absorb heat of an object and the condensation of the evaporated refrigerant at a condenser is repeated. For example, referring to Jeffrey Kirshberg, Dorian Liepmann, Kirk L. Yerkes, "Micro-Cooler for Chip-Level Temperature Control", Aerospace Power Systems Conference Proceedings, (USA), Society of Automotive Engineers, Inc., April (1999), P-341, pp. 233-238.

A conventional device, however, has problems as described below. For example, a silicon substrate and a Pyrex (registered trademark) glass substrate which includes a line pattern formed by etching are bonded by anodic bonded, wherein the silicon substrate includes a wick in an evaporator, a condenser, and grooves for lines formed by dry etching. Water as working fluid is then injected into the composite and vacuum-sealed to complete a CPLs device. After the evaporator is attached to a heat source, operation of the device in accordance with the operating principle of the CPLs causes the areas of the silicon substrate where the wick, the lines and the condenser are formed to discolor, and gas is generated, whereby saturation vapor pressure increases. This gas may interfere with heat transport in

the device to impair the performance of the device and thus may damage the device.

The problem is that there is no an effective method for decreasing the generation of gas. A method which is used for a heat pipe cannot be applied to a small device which is fabricated using MEMS technology because of, for example, the constraint of the size.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to prevent gas generation in a heat-transport mechanism such as a heat-transport device or an electronic device that is suitable for reduction in volume or thickness.

According to a first, a sixth, and a tenth aspects of the invention, the surface of at least one of the wick or the line is subjected to coating treatment, whereby gas generation is blocked or decreased. This treatment can prevent problems (performance degradation or the like) caused by the gas.

According to a second and a seventh aspect of the invention, at least one of the wick or the line is subjected to surface treatment by nitriding, oxidation, or carbonization, whereby the generation of gas is suppressed.

According to a third and an eighth aspects of the invention, at least one of the composite components has

sufficient binding force and stable bonding.

According to a fourth and a ninth aspects of the invention, anodic bonding is not employed, and thus the generation of gas, particularly hydrogen, is blocked.

According to a fifth aspect of the invention, the bonding of components or substrates where the base material is silicon or glass (heat-resistant glass or the like) decreases the effects caused by the gas.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view showing an example of a basic configuration of a heat-transport device according to an embodiment of the present invention;

Fig. 2 is a schematic view showing another example of a basic configuration of a heat-transport device according to an embodiment of the present invention;

Fig. 3 is a diagram for describing a method for treating a surface after anodic bonding;

Fig. 4 is a diagram for describing another example of a method for treating a surface after anodic bonding;

Fig. 5 is a process chart of a method for treating a surface before anodic bonding;

Fig. 6 is a process chart of a method in which surface polishing and reprocessing are skipped; and

Fig. 7 is a process chart showing a method with a

bonding sheet.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention relates to a heat-transport device and an electronic device including a main body a plurality of bonded substrates. Each of the substrates includes a wick, which generates capillary action to reflux working fluid, and a line in which working fluid flows. The present invention, for example, is suitable for a heat dissipating or a cooling system having a heat-transport mechanism based on phase change and circulation of the working fluid. In the application to an information processor such as a computer or a portable device, the use of a heat dissipating or cooling structure according to the present invention for various devices (for example, a CPU, an imaging device, a light-emitting device, a driving motor used in a small hard disk or an optical-media drive, or an actuator under thermally severe conditions) that are heat sources can achieve reduction in volume and thickness, and high efficiency.

A method for manufacturing the heat-transport device according to the present invention includes a step of coating the wick and the inner faces of the lines by ion implantation or the like for preventing gas generation.

Figs. 1 and 2 are schematic views showing basic

structures of heat-transport devices. The term "heat-transport device" includes a device (a main body) for transferring heat from a heat source by working fluid and, in a broad sense, represents an overall system including, for example, a heat source, a cooler, a radiator, or a temperature controller.

In an embodiment shown in Fig. 1, a heat-transport device 1 is provided with an evaporator 2 where a liquid working fluid evaporates and a condenser 3 where a gaseous working fluid condenses. In order to achieve large heat transport capacity, the device preferably has a CPLs structure provided with the evaporator 2 which absorbs heat from a heat producing area shown by the dotted lines and the condenser 3 which condenses the gaseous working fluid into a liquid phase.

The evaporator 2 and condenser 3 each include a structure (wick) which generates capillary action to reflux the working fluid. The wick is composed of grooves, a screen, or a sintered metal. In this embodiment, a groove wick structure is used. Although Fig. 1 shows, for convenience in describing, one evaporator 2 and one condenser 3, the present invention is not limited to a one-to-one correspondence between the evaporator 2 and condenser 3; hence, this embodiment may include a variety of structures which include a plurality of evaporators to one

condenser or a plurality of condensers to one evaporator.

The heat-transport device 1 is provided with lines that connect the evaporator 2 to the condenser 3. The lines include a liquid line 4 where a liquid-phase working fluid flows and a vapor line 5 where a vapor-phase working fluid flows. The liquid-phase line 4 or the vapor-phase line 5 may be a tube, a pipe, a groove, or a channel. Although Fig. 1 shows the simplest structure including one liquid line and one vapor line, a plurality of lines may also be used.

A heat-transport device 6 shown in Fig. 2 has a loop structure where a liquid-phase working fluid circulates, being provided with a wick 7 and a loop line 8. For example, a structure having a transfer pump interconnected on the loop line 8 is known.

The working fluids used in structures shown in Figs. 1 and 2 are, for example, water, ethyl alcohol, methyl alcohol, propyl alcohol (including isomers), ethyl ether, ethylene glycol, Fluorinert (registered trademark), and ammonia.

In any structure having a main body including a plurality of substrates bonded together, grooves constituting lines and microscopic asperities constituting the wick are formed in any one of the substrates.

For example, in a structure where a silicon substrate and a glass (heat resistant glass) substrate are bonded, as described above, operation of a heat-transport device, using

water as working fluid, may cause the area of the silicon substrate where the wick in the evaporator and the lines are formed to discolor, and trace gas is generated.

For the oxidation of a silicon substrate, the oxidized areas on the silicon substrate were analyzed with an analyzer (energy-dispersive X-ray diffraction (EDX)). The results showed that an oxide film (silicon dioxide) was formed. The thickness of this oxide film is larger than the thickness of a natural oxide film. For the gas generated after the operation of the device (heat-transport device), the gas collected by a substitution method in water was analyzed by mass spectrometry. The results showed that the gas was hydrogen. That is to say, it is assumed that an alkaline component such as sodium (Na) migrated from the glass substrate reacts with water to generate hydrogen, and the silicon is oxidized with oxygen.

In the present invention, the surface of the wick and the lines are subjected to coating treatment such as nitriding, oxidation, or carbonization to prevent the generation of gas, in particular hydrogen. In view of surface tension, (1) nitriding, (2) oxidation, or (3) carbonization is preferably employed in that order. The present invention is, however, not limited to these treatments, and thus various surface treatments may be used.

The substrates constituting the main body of a device

are bonded together by anodic bonding, heat seal or the like.

For example, the wick and the condenser having a depth of about 200 μm are formed in the silicon substrate by dry etching (deep reactive ion etching (DRIE)), wherein the wick is composed of grooves each having a width of 30 μm and a depth of about 100 μm . A line pattern having a width of 50 μm and a depth of 200 μm is formed in the heat-resistant glass substrate by sandblasting.

These two substrates are bonded together by anodic bonding in common use for micromachine technology. The (mirror) surfaces of these substrates face each other. The glass substrate is grounded and -500 V is applied to the silicon substrate. These substrates are heated at a predetermined temperature (400°C to 450°C) for a few minutes, and then the migration of sodium ions from Pyrex (registered trademark) glass completes the bonding. (A problem is that the sodium ions react with water to generate hydrogen.)

In a method for manufacturing a heat-transport device, examples of measures to prevent the generation of gas are described below:

(I) In case of anodically bonding the composite components, the surface of the wick or the line is subjected to coating treatment (surface treatment such as nitriding, oxidation, or carbonization); and

(II) The composite components are bonded by any means

other than the anodic bonding, for example, heat seal.

The measure (I) may be any one of the submeasures described below:

(I-1) The surface of the wick or the line is subjected to coating treatment after the composite components are bonded by anodic bonding; and

(I-2) The surface of the wick or the line is subjected to coating treatment before the composite components are bonded by anodic bonding.

The submeasure (I-1) is described referring to Figs. 3 and 4.

Figure 3 illustrates a composite component before and after surface treatment shown on the left and right, respectively.

In this measure, a composite component 9 has a two-layer structure composed of substrates 9A and 9B. For example, the substrate 9A is a silicon substrate including an evaporator 10, a condenser 11, and lines 12 and 12 which are composed of grooves or asperities as shown schematically on the lower left. The substrate 9B is a glass substrate including grooves for lines (not shown).

In the steps after the bonding of the substrates 9A and 9B by anodic bonding, two inlets 13 and 13 for injecting working fluid (refrigerant) are formed, wherein the inlets are connected to pipes 14 which are connected to a device 15

for oxidizing the surface.

The device 15 includes, for example, a steam generator, a device having a circulating structure, and a device for circulating an aqueous hydrogen peroxide solution. Oxidation is performed with these devices (for example, oxidation with a high-temperature and high-pressure steam or an aqueous hydrogen peroxide solution.).

For example, steam with a pressure of 10 atm or more and a temperature of 400°C or more is fed through one of the pipes 14 into the lines and the wick from the device 15; then, the steam is drawn through the other pipe 14 into the device 15. Consequently, the steam is circulated to oxidize the surface of, for example, the lines. The area of the substrate 9B facing the wick and the lines is thereby subjected to oxidation annealing. After the composite component 9 is charged with a working fluid via the inlets 13 and 13, each inlet is sealed by cap or the like.

As shown in Fig. 4, in regard to oxidation by annealing using steam, a unit 16 including a water bath and a heating device may be used. In this embodiment (not using the pipes), steam is fed into the composite component via the inlets for working fluid, and is circulated in the wick and the lines.

The composite component 9 where the inlets 13 and 13 remain open is placed on a mesh (screen) 18. A water bath

19 is heated by a heating device 20 such as heater to generate steam with a temperature of 400°C or more. Oxidation annealing is achieved by the same effect as that shown in Fig. 3. In this embodiment, the unit 16 has a relatively simple structure.

The submeasure (I-2) is described referring to Figs. 5 and 6. A method for the coating treatment of the surfaces of the glass substrate and the silicon substrate before the bonding of these substrates by anodic bonding decreases the generation of gas more than a method for the coating treatment after the bonding (because of the decrease in the migration of sodium from the glass substrate.).

Fig. 5 shows an embodiment of a method for the coating treatment such as oxidation, nitriding, or carbonization to an area forming, for example, the wick and the lines. Two substrates are processed by the following steps:

- (1) Dry etching of a silicon substrate;
- (2) Surface treatment;
- (3) Surface polishing;
- (4) Surface treatment;
- (5) Surface treatment of a glass substrate; and
- (6) Anodic bonding.

In step (1), grooves or asperities are formed on a substrate 21A by dry etching.

In step (2), for example, the walls of the wick and the

inner face of the lines are subjected to surface treatment by ion implantation, thermal oxidation, or steam oxidation. The surface treatment may be applied to the entire surface or selected areas of the surface through a mask.

In step (3), the surface is polished by dry etching, plasma treatment, or the like. In step (4), a further surface treatment is performed with a mask 22 (the polished surface is covered.). For example, an area other than the areas of the wick and the lines and the like is masked by the mask 22 and then subjected to surface treatment by ion implantation. Coating treatment is selectively performed to only a desired area.

Ion implanters for semiconductors and plasma-based ion implantation (PBI) can be use. (Isotropic ion implantation based on plasma can be used in the surface modification of components of complex shape, inexpensively and with high productivity.) Since the amount of ions implanted in the surface is important, surface treatment is preferably performed at an implantation energy between 10 and 200 KeV (kiloelectron volt). Ions for ion implantation are preferably gas ions such as oxygen, nitrogen, and carbon (methane).

In step (5), after a glass substrate 21B (heat-resistant glass) is masked to protect the bonding face, a thin film of silicon dioxide (SiO_2) or the like is formed by

vapor deposition.

In step (6), the glass substrate 21B treated in step (5) and the silicon substrate 21A are bonded by anodic bonding.

In thermal oxidation, the entire surface of the silicon substrate 21A is subjected to surface treatment in the first surface treatment; hence, a further surface treatment is performed after surface polishing so as not to interfere with the following anodic bonding. Alternatively, only the required area of the silicon substrate 21A may be subjected to surface treatment using the mask, steps (3) and (4) are skipped to go to step (5), and then the silicon substrate 21A and the glass substrate 21B may be bonded in step (6).

For example, in Fig. 6, in order to eliminate the steps of surface polishing and re-treatment, substrates are processed by the following steps:

(1) Forming a sheet 25 by bonding a polyimide sheet 23 such as a Kapton (registered trademark) sheet with a thickness of 0.125 mm, manufactured by DuPont and a thermoplastic olefin sheet 24 by thermocompression;

(2) Forming a mask sheet 26 for protecting a bonding face by stamping the sheet 25, which is made in step (1), using an ultraviolet yttrium aluminum garnet (UV:YAG) laser;

(3) Forming, for example, grooves on the silicon substrate 27A by dry etching;

(4) Temporary crimping the mask sheet 26, which is made in step (2), with the silicon substrate 27A, which is processed in step (3), at room temperature;

(5) Implanting ions such as oxygen, nitrogen, or carbon ions (pulsed implantation is performed at an energy of 20 KeV or less);

(6) Completely eliminating residues by plasma ashing after peeling off the mask sheet 26 in an organic solvent such as acetone, isopropyl alcohol, or ethyl alcohol; and

(7) Bonding a glass substrate 27B with the silicon substrate 27A by anodic bonding.

This embodiment requires making the mask sheet 26, in steps (1) and (2), but requires a single surface treatment only.

Fig. 6 illustrates a plan view of a substrate and cross sectional view taken along the dashed line in each of steps (3), (4), (6), and (7).

The measure (II), which does not include the anodic bonding step, is described referring to Fig. 7. The process is described below:

(1) A step of forming grooves in a silicon substrate 28A by dry etching;

(2) A step of surface treatment (ion implantation, thermal oxidation, or steam oxidation);

(3) A step of processing (stamping) a thermoplastic

polyimide sheet with UV:YAG laser;

(4) A step of aligning a bonding sheet 29 with the grooves formed by dry etching in the silicon substrate 28A;

(5) A step of placing a glass component 28B on the silicon substrate 28A with a bonding sheet 29; and

(6) A step of thermally fusing with the bonding sheet 29 by vacuum press (for example, object is pressed with 3.92×10^6 Pa (40 Kg/cm²) at vacuum pressure of 1×10^{-3} Pa and a temperature of about 330°C for 10 minutes to complete bonding).

The glass component 28B requires that the coefficient of linear expansion has substantially the same as silicon or close to silicon. For example, boron oxide (B₂O₃) monocomponent-based glass or HCD-1 (registered trademark, manufactured by OHARA INC.) has the coefficient of linear expansion of between about 3×10^{-6} and 4×10^{-6} . Non-alkaline glass is preferably used.

The bonding sheet is, for example, a thermally fusing polyimide film Upilex-VT (registered trademark, manufactured by Ube Industries, Ltd.).